

BEHAVIOUR MONITORING OF A PRESTRESSED CONCRETE SLAB LOADED BY DYNAMIC FORCE

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ABSTRACT: To obtain a better knowledge of existing structures behaviour monitoring can be used. The aim is to monitor the behaviour of a structure accurately and efficiently, to detect damage or deterioration, and to determine the health or condition of the structure. The objective of this behaviour monitoring of the prestressed concrete slab was to investigate the changes of the modal characteristics of the slab in dependence on the high intensity dynamic cyclic loading. Before the test and after each 250 000 loading cycles the dynamic response of the slab was measured with a separate test arrangement. Modal characteristics of the slab, which were measured after each load step, were mutually compared. Changes of natural frequencies $\Delta f_{(j)}$ of the slab were computed first. For the comparison of natural modes, changes of a mode surface curvature $\text{CAMOSUC}_{(j),x}$, changes of a modal flexibility matrix $\Delta [\delta]$ and the second derivative of changes of diagonal members of a modal flexibility matrix $\Delta [\delta]''$ were used.

KEY WORDS: fatigue, natural frequency, natural mode, prestressed concrete, modal analysis

1. INTRODUCTION

In present days, traffic speed increases, the number of vehicles rapidly increases and they are much heavier and structures become inherently weak. This is why dynamic forces and fatigue loads caused problems on structures. New methods for monitoring of structure conditions and damage detection of a structure at the earliest possible stage are needed. The advantage of methods, which use results of an experimental modal analysis for estimation of a degradation degree of a structure, is that they can be applied to complex structures. These methods are suitable to verify on simple structural elements where we know their damage state.

The experiment described in this paper is focused on monitoring of the influence of high intensity fatigue loading on the change of the modal characteristics of the fully prestressed concrete structures, which are designed to be no tensile stress there when maximum design load is applied.

2. DESCRIPTION OF THE PRESTRESSED CONCRETE SLABS

For the purpose of this project, SMP CONSTRUCTION a.s. made three prestressed concrete slabs. The dimensions of the slabs were 130 x 1155 x 4500 mm with ends expanded to the height 400 mm for tie of the prestressing bars (Fig. 1). Slab was made from concrete C45/55 with eleven prestressing cables of diameter 15.7 mm. The slabs were put on two bearing to be a simply supported with the span 3500 mm with cantilevered ends 500 mm on both sides (Fig. 1).

The tested slabs were designed as a fully prestressed concrete slabs according EN1992-2 to not comply the safety condition in the lower part of the slab when the high intensive cyclic loading is applied.

3. FATIGUE LOAD OF THE SLAB

Tests of the slab were carried out in laboratories of Faculty of Civil Engineering, CTU in Prague. The prestressed concrete slab was loaded in four point bending to get a constant bending moment in the mid-section of the slab (Fig. 1). The cyclic load was applied to the slab in several steps. This fatigue load of the slab was induced by harmonic force with frequency 5 Hz. The amplitude of the dynamic load was chosen to not comply the safety condition for the fatigue loading of the concrete according to ČSN EN 1992-1-1 and EN 1992-2 described in [1].

$$\frac{\sigma_{c,max}}{f_{cd,fat}} \leq 0.5 + 0.45 \frac{\sigma_{c,min}}{f_{cd,fat}} \leq 0.9 \; , \tag{1}$$

where $\sigma_{c,max}$ is the maximal compressive stress, $\sigma_{c,min}$ is the minimal compressive stress and $f_{cd,fat}$ is the design compressive strength of the concrete.

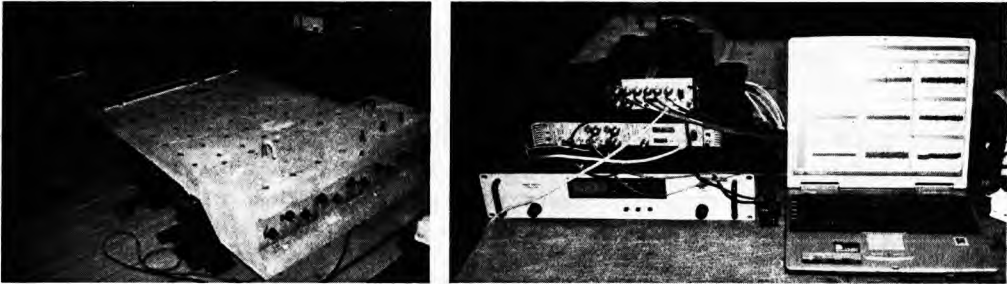


Fig. 1: The prestressed concrete slab and the measurement system

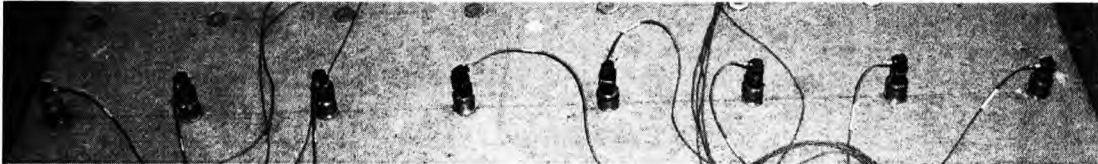


Fig. 2: The piezoelectric acceleration transducers Bruel & Kjaer 4507 B 005

3. DATA ACQUISITION

The dynamic cyclic loading stopped after each 250 000 cycles and an experimental modal analysis was carried out. The Modal Exciter Type 2732 (Bruel & Kjaer) was used for the excitation of the prestressed concrete slab. The exciter was placed under the slab (Fig. 1) linked to the slab with the flexible drive rod. The exciter produced a random driving force over the frequency range of 5 to 400 Hz. The force transducer Endevco 2311-10 placed between the flexible rod and the slab measured the excitation force. The response of the element onto forcing by the exciter was measured by three piezoelectric acceleration transducers Bruel & Kjaer 4507 B 005 (Fig. 2) in a chosen net of points on the upper face of the slab (27 cross-sections and 8 points in each cross-section) (Fig. 1). Later the measurement system (Fig. 1) was completed to eight transducers and so the whole cross-section can be measured at a time. The point of excitation was designed to be able to excite basic bending modes

of natural vibration of the slab. Values of the Frequency Response Function (Fig. 3) were obtained as an average from ten measurements. The window length of the time signal processing was 32 s, the frequency range of the window was set to 400 Hz.

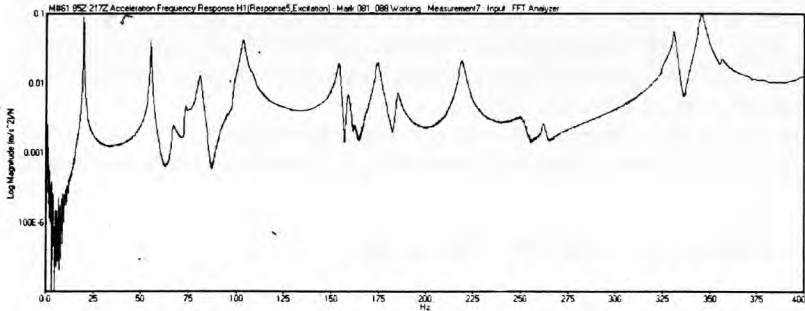


Fig. 3 The example of the FRF in the point No.85 in the state of the slab No. 1 after 3 500 000 cycles

4. MODAL CHARACTERISTICS EVALUATION

The program MEscapeVES (Bruel & Kjaer) was used for modal characteristic evaluation from measured Frequency Response Functions (Fig. 3). With regard to a frequency range of the dynamic analysis 5-400 Hz nine natural frequencies and mode shapes were evaluated. Examples of the natural mode shapes evaluated in a virgin state of the prestressed slab No. 2 are shown in Fig. 4.

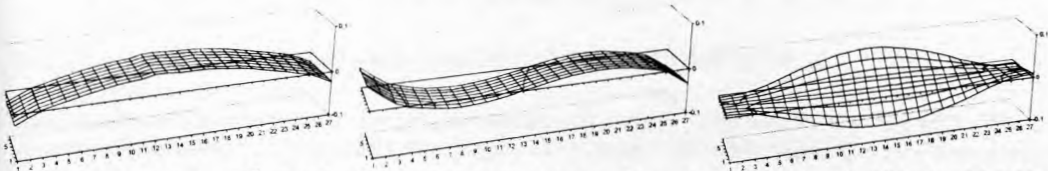


Fig. 4 The 1st, the 2nd and the 3rd natural mode shapes of the slab No. 2 ($f_1=19.3$ Hz, $f_2=53.9$ Hz, $f_3=97.1$ Hz) in virgin state

5. COMPARISON OF MODAL CHARACTERISTICS

Modal characteristics of the slab, which were measured after each load step, were mutually compared. For comparison of natural modes, changes of a mode surface curvature CAMOSUC(j),x were used

$$\text{CAMOSUC}_{(j),x} = \left| \frac{r_{(j)XX,x+1} - 2r_{(j)XX,x} + r_{(j)XX,x-1}}{h^2} - \frac{r_{(j)YY,x+1} - 2r_{(j)YY,x} + r_{(j)YY,x-1}}{h^2} \right|, \tag{2}$$

where $r_{(j)XX,x}$ is the value of the j-th natural mode shape in the x-th measured point in one damage (or virgin) state XX of the slab, $r_{(j)YY,x}$ is the value of the j-th natural mode shape in the x-th measured point in another damage state YY of the slab and h is the dimension of the net of measured points. Then the changes of a modal flexibility matrix $[\delta]$ (Fig. 5-6) were used for comparison of natural modes

$$[\delta] = [R_{(j)}][1/\omega_{(j)}^2][R_{(j)}]^T, \tag{3}$$

$$\Delta\delta_r'' = \frac{\Delta\delta_{r,x+1} - 2\Delta\delta_{r,x} + \Delta\delta_{r,x-1}}{h^2}, \tag{4}$$

where $[R_{(j)}]$ is the modal matrix composed of n measured natural modes and $[1/\omega_{(j)}^2]$ is the diagonal matrix composed of natural angular frequencies $\omega_{(j)}^2$. The last method used for comparison of natural modes was the second derivative of changes of diagonal members of a modal flexibility matrix $\Delta[\delta]''$ (Fig. 5-6). $\Delta\delta_{r,x}$ is the change of the diagonal member r of the modal flexibility matrix and h is the distance of the net of measured points.

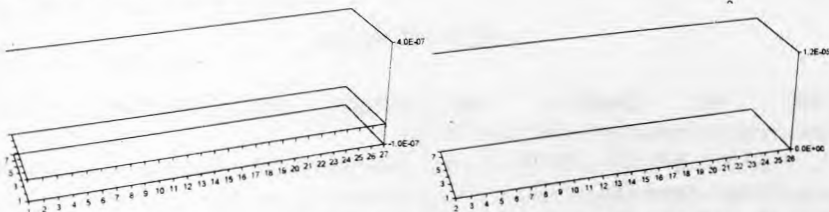


Fig. 5 The $\Delta[\delta]$ and $\Delta[\delta]''$ between the virgin state and the state after 3 500 000 loading cycles of the slab No. 1.

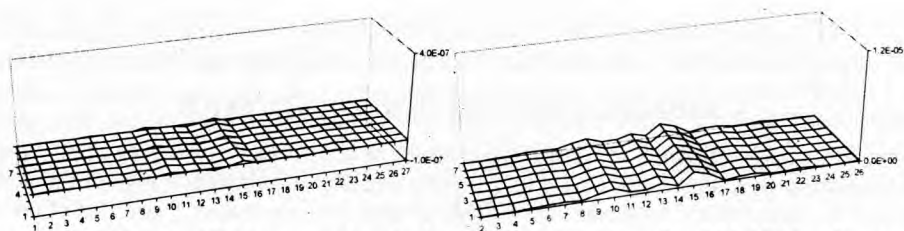


Fig. 6 The $\Delta[\delta]$ and $\Delta[\delta]''$ between the virgin state and the state after 250 000 loading cycles of the slab No. 2.

6. FINITE ELEMENT MODEL OF THE SLAB

The model of the slab was created using Finite Element Method (Fig. 7). Computed modal characteristics were compared with experimentally estimated ones. The same methods were used for this comparison as for the comparison between experimental modal characteristics from two damage states.



Fig. 7 The examples of the mode shapes of the model of the slab ($f_1=19.8$ Hz, $f_2=54.9$ Hz, $f_4=101.4$ Hz).

7. CONCLUSION

The behaviour monitoring of prestressed concrete slabs loaded by dynamic cyclic fatigue load was the main aim of this long-time experiment. The changes of the modal characteristics of the fully prestressed concrete slab in dependence on number of the loading cycles was monitored. The modal characteristics after several loading steps (each step is equal to 250 000 loading cycles) were evaluated. The examples of mode shapes of the prestressed concrete slab and of its model are shown in Figures 4 and 7. Mode shapes were mutually compared using three different methods: CAMOSUC_{(j),x}, $\Delta[\delta]$ (Fig. 5 - 6) and $\Delta[\delta]''$ (Fig. 5 - 6). The changes of previous functions between virgin state and state after 3 500 000 cycles are not very big as you can see in Figure 5. Some changes can be seen in the middle part of the slab. Nevertheless, these changes in dynamic behaviour are not significant even after the end of theoretical fatigue lifetime of the first investigated slab. Also on the second slab there are only small changes in its dynamic behaviour after the first 250 000 loading cycles (Fig. 6). The monitoring still continues. More measurements will be done on the second slab and one more identical slab will be investigated in the same manner to make conclusions that will be more general.

9. REFERENCES

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